AD 294 944

First Quarterly Progress Report

1 May 1962 - 1 August 1962

Report No. 1

Contract No. DA-36-039-SC-89163

Department of the Army
Project No. DA-3A99-21-001

DISTRIBUTED JUNCTION TUNNEL DIODE OSCILLATOR

PHASE II.

U.S. Army Signal Research
& Development Laboratory

Fort Monmouth, New Jersey

MICROWAVE ASSOCIATES, INC.

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U.S. Army Signal Research & Development Laboratory

Fort Monmouth, New Jersey

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Research Objective: To investigate the feasibility of creating distributed junction tunnel diode oscillators capable of yielding higher powers at higher frequencies.

II. TABLE OF CONTENTS

III. PURPOSE

The purpose of this contract is to conduct a theoretical and experimental feasibility study for higher frequency high power tunnel diode oscillators. In particular, the design principles and criteria will lead to the design of a distributed junction tunnel diode oscillator capable of giving power outputs in excess of 10 mw at 10 KMc. Included as part of the study shall be the consideration of appropriate microwave circuit environments for maximum oscillator efficiency and stability.

IV. ABSTRACT

Efforts to determine the feasibility of constructing 10 mw 10 KMc tunnel diode oscillators have been continued and diode requirements for these oscillators have been determined. Various materials, doping elements, and fabrication techniques have been investigated to determine the best combination of these to potentially meet the frequency and power requirements.

Two packaged diode and two distributed diode oscillators have been built. The packaged spot diode oscillators have been operated at 10 KMc, but it is obvious from the results obtained that these oscillators will not meet the contract target of 10 mw at 10 KMc. However, the experience gained from using the spot diodes have been useful in improving the distributed junction diode oscillators. Contacting problems have held back test results with both the ring distributed and strip line distributed tunnel diode oscillators.

Fabrication of distributed junction diodes has been continued. The contacting problem will be discussed in more detail in the body of the report.

V. PUBLICATIONS, LECTURES, REPORTS, AND CONFERENCES

There have been no publications, lectures, reports, or conferences as a result of this contract during the last quarter.

VI. FACTUAL DATA

A. INTRODUCTION

The purpose of this contract is to determine the theoretical and experimental feasibility of building a tunnel diode oscillator that will operate at 10 KMc producing 10 or more mw of power output with a 20% tuning range.

Oscillations in tunnel diodes occur in the negative resistance portion of the curve. The power obtainable from these tunnel diodes during oscillation depends on the magnitude of the voltage swing in the negative resistance region and on the magnitude of the current change. The available power from an oscillating tunnel diode (P) then depends on $(V_v - V_p)(I_p - I_v)$; for high peak to valley ratio tunnel diodes this value becomes $\approx (V_v - V_p)\, I_p$. The amount of this power that is available from a tunnel diode oscillating depends on the cutoff frequency of the diode and operating frequency. Useful power

$$P_o = P\left[1 - \left(\frac{F_o}{F_r}\right)^2\right]$$

where P = maximum theoretical power

F_o = operating frequency

F_r = diode resistive cutoff frequency

Other things being equal, the F_r depends on current density. Therefore, to make a high power tunnel diode capable of operating at 10 KMc, two things are necessary. First, one must obtain the diode material with the maximum negative resistance voltage length; and secondly, it must have a high peak tunnel current density to give high cutoff frequency. For a

10 KMc oscillator, the diodes resistive cutoff frequency should be well in excess of 10 KMc so that the available power is not diminished too greatly. An oscillator containing a single spot diode capable of putting out 10 or more mw at X band would have to employ a tunnel diode with peak current in excess of half an ampere with a cutoff frequency approaching 20 KMc. The impedances associated with such a large diode are in the order of tenths of ohms making the circuit stability problem almost impossible.

Our approach to solving these impedance values has been twofold.

1. To improve smaller spot diodes with reasonable impedances and employ these small spot diodes in a lump distributed oscillator capable of producing 1 - 10 mw at X band; and,

2. To build a true distributed junction tunnel diode oscillator capable of producing 10 or more mw at X band, and to incorporate this distributed diode into an oscillator. To accomplish this, effort has been expended in the following areas:

1. Tunnel diode oscillator circuitry and fabrication

2. Fabrication of spot gallium arsenide and germanium tunnel diodes for the use in these single diode oscillators

3. Fabrication of distributed junction gallium arsenide tunnel diodes

4. Fabrication of distributed tunnel diode oscillators

5. The microwave characterization of these diodes

B. TUNNEL DIODE OSCILLATOR DESIGN AND FABRICATION

During the past quarter four tunnel diode oscillators were designed and fabricated. These included an S band packaged diode oscillator,

an X band packaged diode oscillator, an X band distributed line oscillator, and finally, an X band distributed ring diode oscillator. Descriptions of these oscillators follow:

1. The S band spot diode oscillator consisted of two diodes mounted in series on spring fingers with a backing plunger for tuning. Some problems were encountered with biasing the two tunnel diodes in series as the second diode tended to switch rather than oscillate. Single diodes used in this oscillator give power outputs in excess of 100 μw.

2. Using the experience gained in this S band oscillator, an X band spot tunnel diode oscillator was designed employing a ridge waveguide in 4x9 waveguide with a ridge gap of twenty thousandths, see Figure #1. Bias was applied to a single diode through a high capacity RF bypass. A low inductance contact to the diode was accomplished by holding the prong in a set of spring fingers on one end and making a pressure contact to the base of the ridge at the other end. Tuning of the diode was accomplished by a shorting plunger behind the diode and slide screw tuners. Using small peak current germanium and gallium arsenide diodes, (diodes with peak currents are from 1 - 5 milliamps), power outputs at 8 - 10 KMc of more than 30 microwatts were obtained. This output was less than 3 db down from that which might be theoretically expected from the diodes. Impedance problems occurred when trying to use diodes with much larger peak currents and the same cutoff frequency. Work during this quarter will attempt to rectify this problem and to employ these principles on a multi diode X band oscillator.

3. An X band distributed line junction oscillator (Figure #1) was built in the following fashion. A ridge guide with a small ridge gap of four

thousandths was used in a 4x9 waveguide. Mechanical difficulties due to the close ridge spacing made it difficult to make a good electrical contact to the distributed line junctions. Once again, the tuning of this diode was accomplished by a shorting plunger behind the diode and slide screw tuners. The difficulties encountered in making a good electrical contact to the entire length of the distributor junction gave very poor results with this unit. Both the contacts to the line distributor junction and the spacing in the ridge guide are being modified to eliminate this problem.

4. An X band distributed ring junction tunnel diode oscillator (Figure #2) employing a conical cavity has been designed and built. Several diodes were fabricated for this oscillator but once again the mechanical contact troubles which plagued the distributor line oscillator have held up results on this oscillator too. The improved contacting method to the distributed line junction in that oscillator should be applicable to the ring structure.

C. <u>SPOT TUNNEL DIODE RESULTS</u>

1. <u>Gallium arsenide fabrication</u>.

Improvements in the alloying technique have made a further improvement in the cutoff frequency of spot gallium arsenide tunnel diodes. By increasing the speed of the alloying cycle, it was possible to further increase the current density of spot gallium arsenide diodes to where it is now possible to make diodes with peak currents of more than 100 milliamps which have cutoff frequencies in excess of 10 KMc. Once the circuit impedance problems in the spot X band oscillator have been eliminated, it should be possible to incorporate several of these package diodes into an X band

oscillator to obtain power outputs approaching 1 milliwatt.

2. Spot germanium tunnel diodes.

The improved fabrication techniques which increase the current density of gallium arsenide diodes also increase the current density of germanium tunnel diodes making it also possible to make germanium tunnel diodes cutoff frequency in excess of 10 KMc with peak currents of more than 100 milliamps. Although large current germanium tunnel diodes are inherently lower power devices than are the gallium arsenide units due to the smaller total voltage swing in the negative resistance region, these diodes have higher cutoff frequencies which compensates for the extra maximum power available from the gallium arsenide tunnel diodes. Once again, these diodes will be tested in the X band oscillator.

D. FABRICATION OF DISTRIBUTED JUNCTION TUNNEL DIODES

Because of the inherent advantages of preparing a thin skin on gallium arsenide due to the amalgamous diffusion of zinc in the gallium arsenide, and because it also has greater power capabilities for the same peak current diodes, it has been decided to concentrate on the fabrication of distributed junction tunnel diodes in gallium arsenide.

Our approach to preparing a distributed junction tunnel diode has been to use the thin skin technique which was discussed previously. Basically, the technique consists of fabricating a very thin layer (less than 1 micron thick) of very highly doped P type gallium arsenide on a semi-insulating base. The tunnel junction is then alloyed through this thin, highly doped layer into the substrate. The tunnel junction then consists of merely the periphery of the alloy region, and by controlling the thickness of the thin skin, it is possible to accurately control the dimensions of the tunnel

junction. The extra capacity contributed by the semi-insulating substrate is small compared to the capacity contributed by the tunnel junction. Therefore, it does not greatly derate the cutoff frequency of the diode.

The circuitry of the present distributed line junction, X band oscillator requires a distributed tunnel junction approximately 75 thousandths long. Therefore, present efforts have been concentrated on fabricating junctions of this length. Diodes with peak currents varying from a few milliamperes to more than an ampere have been fabricated merely by changing the diffusion time of the thin skin. These diodes have peak current to capacity ratios, ranging up to 8 to 1, indicating current densities in the tunneling region in the order of 50 to 100,000 amperes per centimeter. These diodes will be tested in the X band oscillator as soon as the ridge height and the contacts are modified.

E. MICROWAVE AND OSCILLATOR CHARACTERIZATION OF SPOT AND DISTRIBUTED TUNNEL DIODES

Considerable effort was employed to improve the means of measuring negative resistance, series resistance, and the oscillator characterication of spot and distributed tunnel diodes. The major problem when measuring series resistance by dc measurements with very large current tunnel diodes is the power dissipation. The usual method for measuring series resistance of a tunnel diode is to bias the diode at many times the peak current in the reverse direction. The slope of the reverse characteristics in this region is a good approximation of the series resistance of the diode and when the current approaches infinity the slope of the line will be the series resistance of the diode. By building a dc pulsing supply with a very low repetition rate with pulse capabilities

up to several amperes, (Figure #3), it is possible to measure directly the series resistance of any tunnel diode regardless of the size without destroying the tunnel diode. Pulse lengths typically are approximately .10 of a microsecond and repetition rate $\approx 10^3/$ sec. This technique has greatly improved with reproducibility of series resistance measurements and gives results which are directly applicable to oscillator measurements.

The 30 megacycle amplifier mentioned in Phase 1 of this contract has been approved by the addition of precision resistors to make it more accurate. Finally, using the X band oscillator, it has been possible to correlate the static characteristics obtained on small current tunnel diodes with the dynamic characteristic of these same diodes when operating an oscillator at X band. Correlation has been good.

VII. CONCLUSIONS

Considerable progress has been made in the fabrication and building of X band oscillators, both of the spot diodes and distributed junction diode type. Initial results with an X band package diode oscillator and using small current diodes have given power outputs in excess of 30 microwatts. Improvement in the circuitry so that lower impedance spot tunnel diodes may be used should make it possible to use this packaged diode oscillator at powers well in excess of 100 microwatts at 10 KMc. The X band distributed line and ring oscillators have been designed and built. Contacting problems to the line and ring distributed junctions have held up test results on these oscillators. These problems should be eliminated by changes now being made.

The cutoff frequency of large current 100 milliamperes or more germanium and gallium arsenide spot tunnel diodes have been increased to more than 10 KMc. These diodes when used in a multi diode packaged X band oscillator should be capable of producing close to 1 milliwatt power output. To achieve the 10 milliwatt output at X band power it will be necessary to go to the distributed junction structures now being built.

Considerable progress has been made in the problems of contacting and reducing the series resistances incurred on both the distributed and ring tunnel diodes. This problem, however, continues to be the major road block standing in the path of making distributed junction tunnel diode oscillators with large power outputs.

VIII. PROGRAM FOR NEXT INTERVAL

The program for the next quarter will consist of the following:

1. Design and construction of a multi diode X band oscillator employing several large current high cutoff frequency packaged tunnel diode in series. By seriesing these diodes, it is possible to increase the impedance level of the microwave circuitry; meanwhile, obtaining larger power outputs because the output of each diode is additive.

2. Efforts will be made to eliminate the mechanical and electrical contact problems encountered in the distributed line and ring X band oscillators through improved contacting procedures for both the oscillator circuitry and the distributed tunnel diode junction itself.

3. Ring distributed and line distributed tunnel diodes will continue to be fabricated. Efforts to improve the static characterization of these diodes and to incorporate these diodes into an X band oscillator capable of giving more than 1 milliwatt at 10 KMc will be continued.

4. Material investigations will be continued to further improve the fabrication of the distributed ring and line structures. Included in this will be an attempt to improve both the mechanical structure of the diodes and the electrical characteristics by a novel fabrication technique.

IX. IDENTIFICATION OF PERSONNEL

The following key technical personnel contributed to this study:

Name	Title	Hours
Dr. Kenneth E. Mortenson	Project Director	44
Charles M. Howell	Project Engineer	60
Carmen Genzabella	Semiconductor Engineer	89
Robert Galvin	Circuit Engineer	62
Robert Tenenholtz	Circuit Engineer	82

Biographies of these people have been given in previous quarterly reports during Phase I of this contract.

LIST OF ILLUSTRATIONS

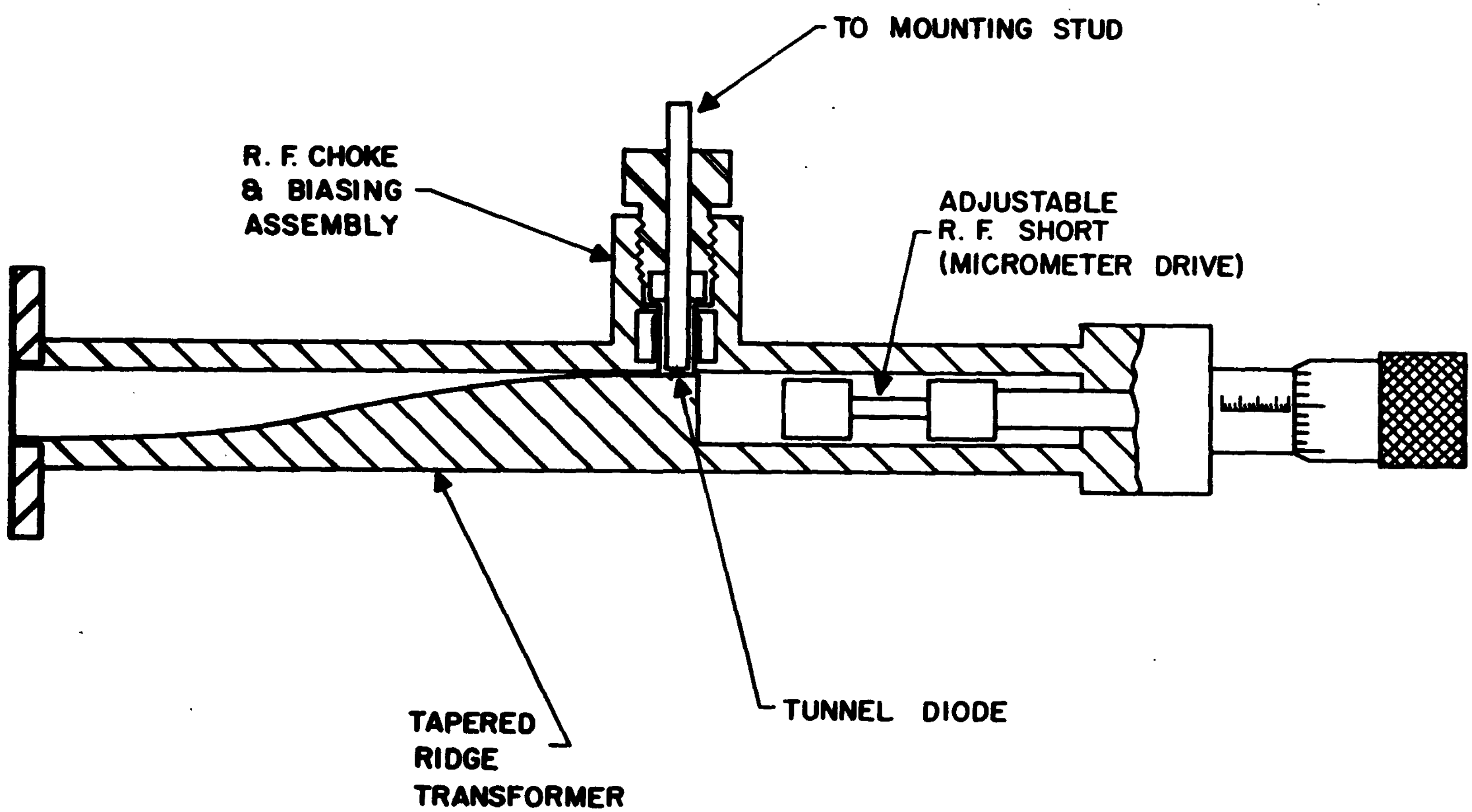


FIGURE I

X BAND TUNNEL DIODE MOUNT

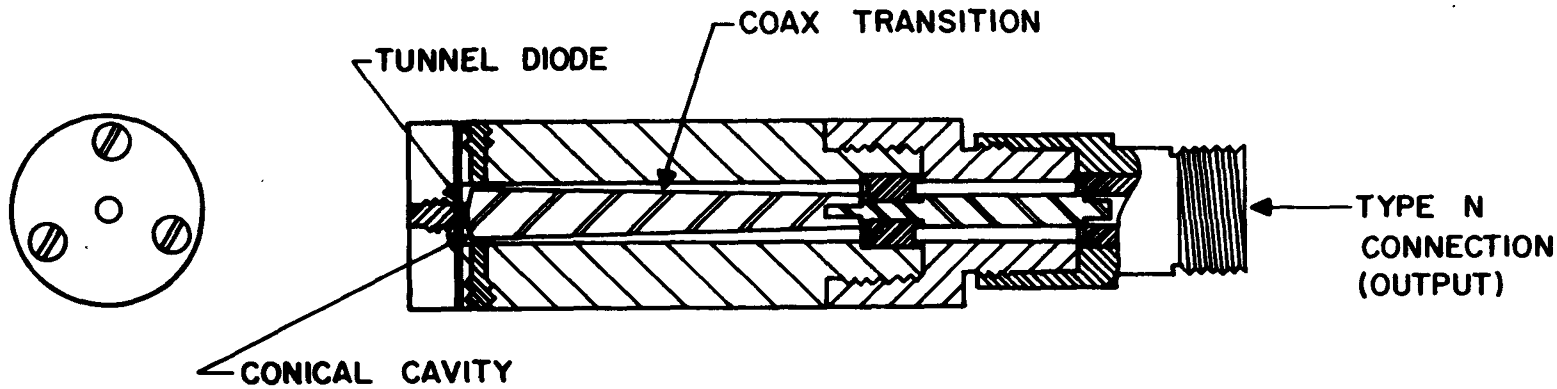
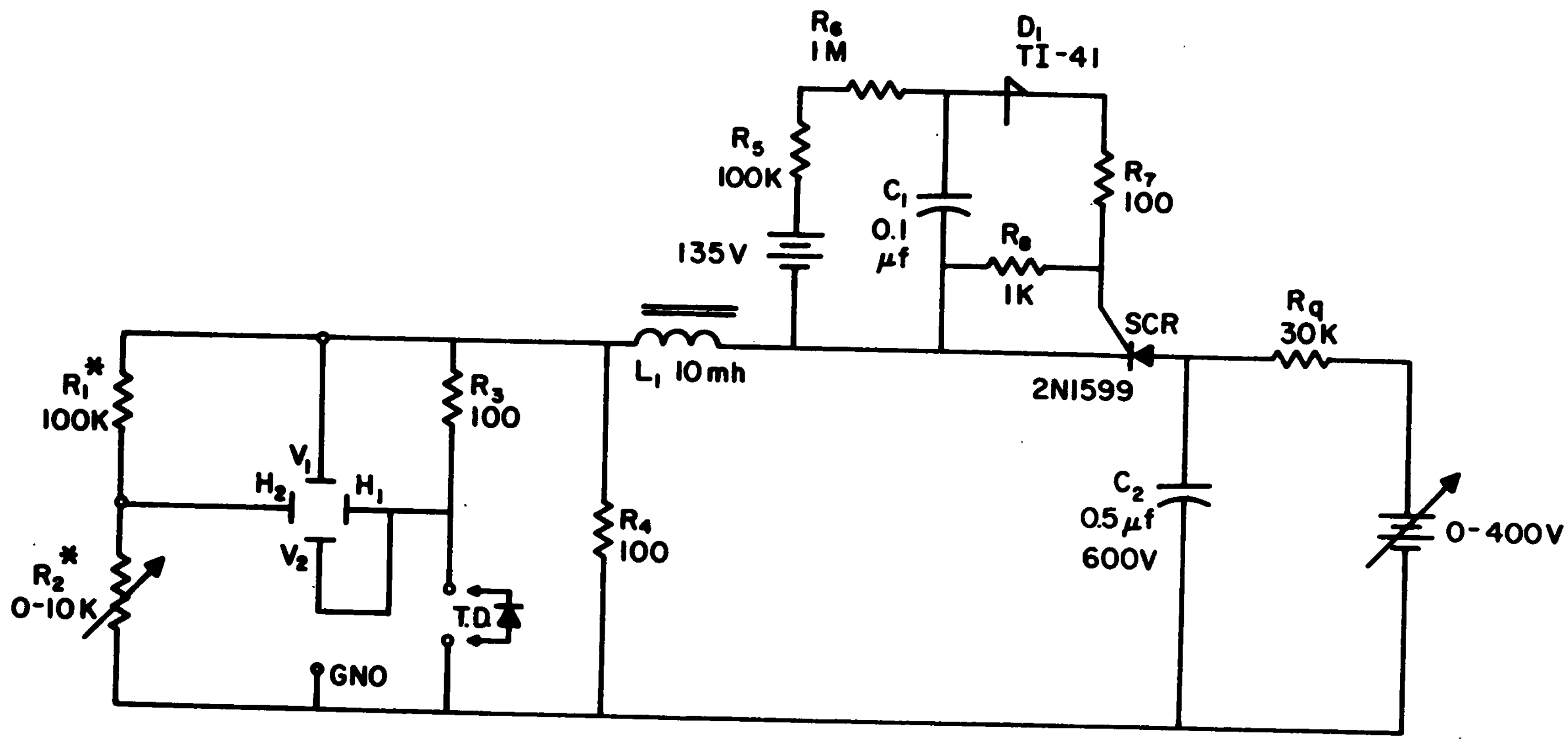


FIGURE 2

CONICAL CAVITY TD OSC.



R_S PULSE TEST CIRCUIT

NOTES: SCHEMATIC, "TUNNEL DIODE SERIES RESISTANCE MEASUREMENT"
BONIN, E.L. AND BAIRD, J.R., TEXAS INSTRUMENTS INC.
R_2 IS DECADE RESISTOR FOR 10 OHM STEPS
* PRECISION NON-INDUCTIVE
SCOPE IS HEWLETT PACKARD 130B OR SIMILAR

FIGURE 3

AD ______________ Accession No. ______________

MICROWAVE ASSOCIATES, INC.
BURLINGTON, MASSACHUSETTS

DISTRIBUTED JUNCTION TUNNEL DIODE OSCILLATOR - PHASE 2

C. Howell

First Quarterly Progress Report, 1 May 1962 - 1 August 1962

20 pp. - Illus., Signal Corps Contract DA-36-039-SC-89163

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Fabrication of distributed junction diodes has been continued. The contacting problem will be discussed in more detail in the body of the report.

UNCLASSIFIED

1. Distributed Junction Tunnel Diode Oscillator

2. Contract No. DA-36-039-SC-89163

AD ______________ Accession No. ______________

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